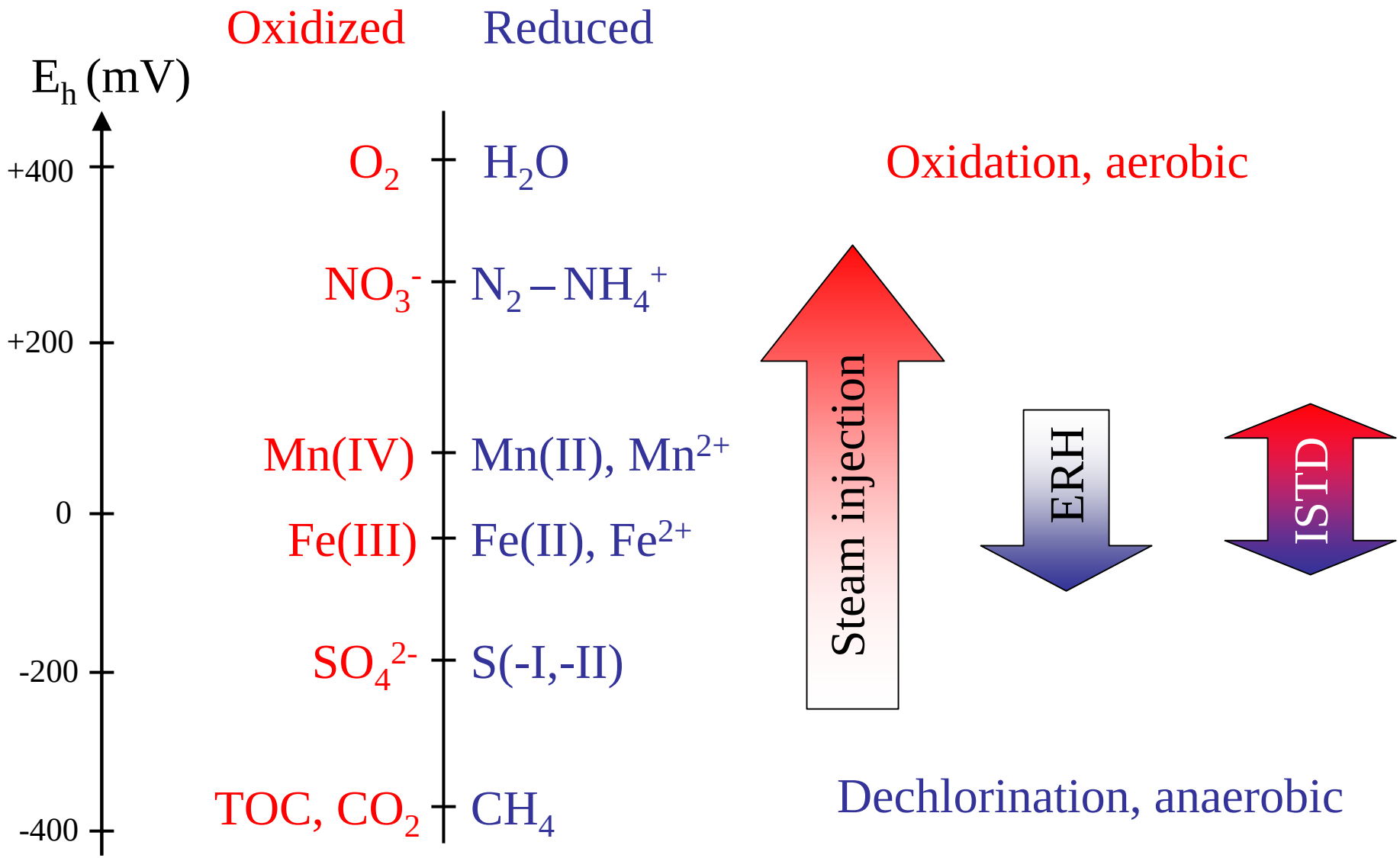
Redox ladder – electron donors and acceptors



Impact of thermal on redox

Steam injection:

- Air: Reduce risk of NAPL condensation
- Air: Enhance removal in vapor phase
- Air/O_2: Stimulate degradation reactions

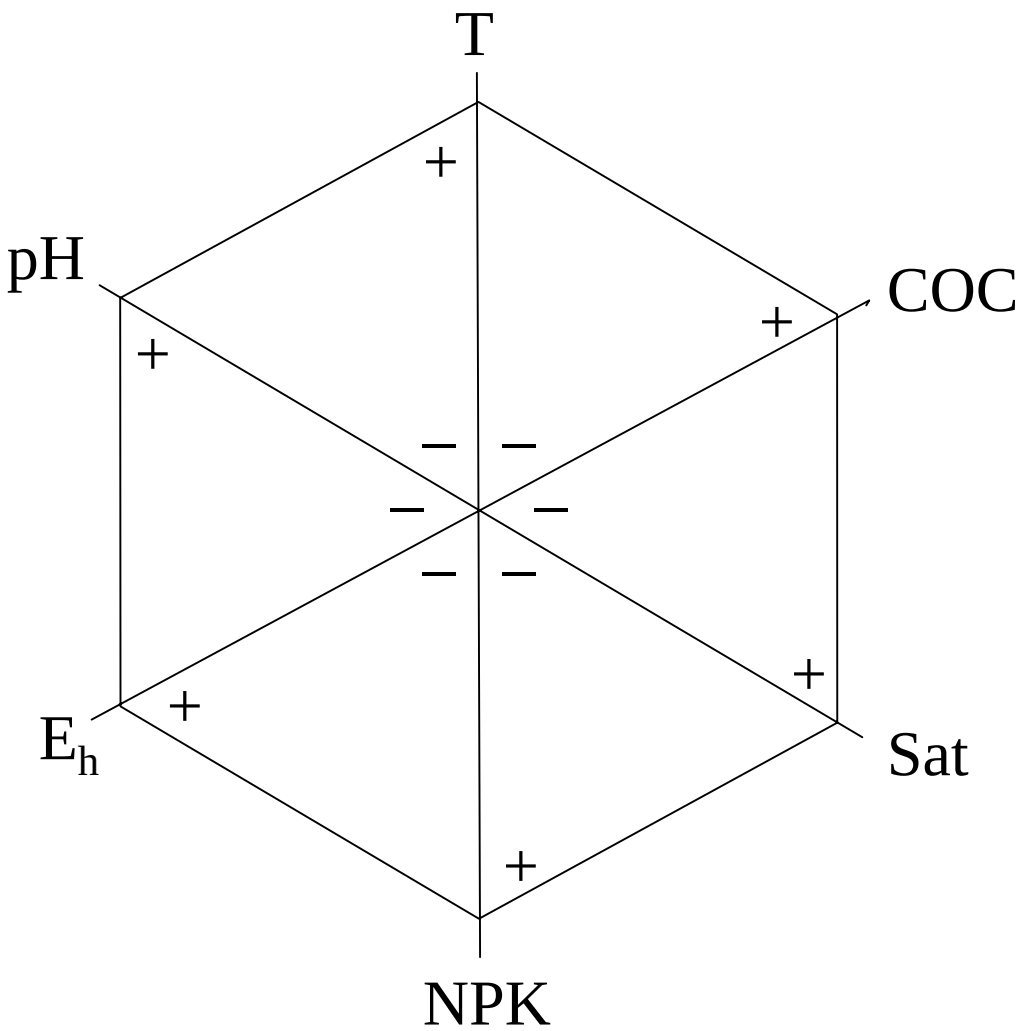
ERH:

- Boiling under vacuum – removes dissolved gases such as O_2
- Hydrogen formation around electrodes possible
- Reactions around Fe(0) used for electrodes

ISTD-TCH:

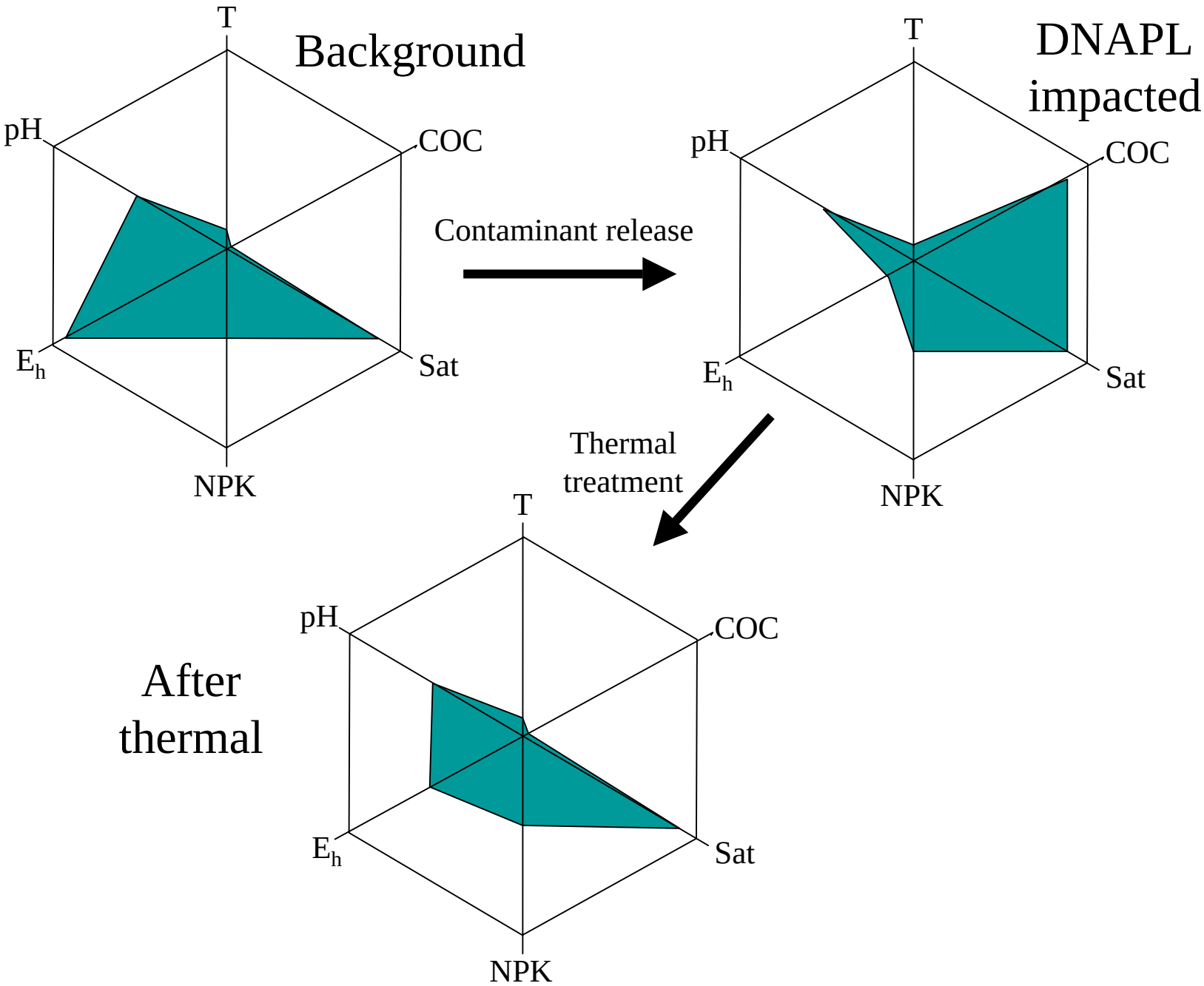
- Boiling under vacuum – removes dissolved gases such as O_2
- Air can be added for in-situ destruction

Environment diagram



Abbreviations

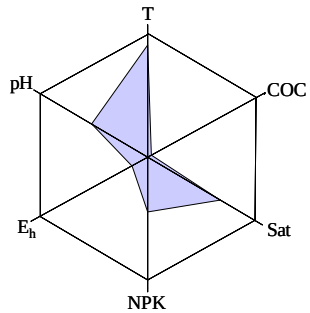
T	Temperature
COC	Contaminant concentration
Sat	Water saturation
NPK	Nutrient availability
Eh	Oxidation-reduction potential


Background
T
pH
COC
Sat
NPK
Eh
Contaminant release
DNAPL
impacted
T
pH
COC
Sat
NPK
Eh
Thermal
treatment
After
thermal
T
pH
COC
Sat
NPK
Eh

Conclusions

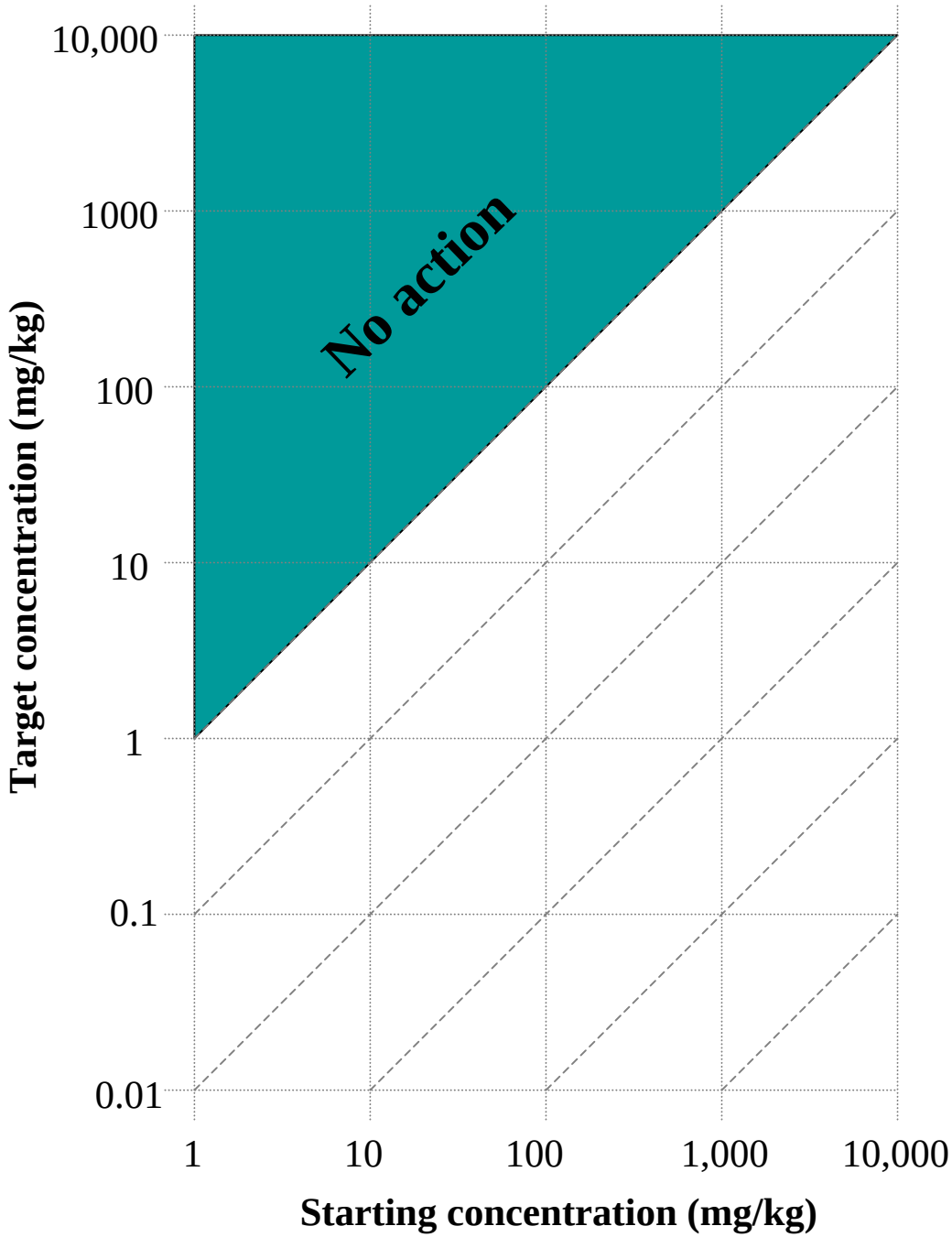
Redox chemistry is key for reactions

Geochemical changes can be significant during thermal

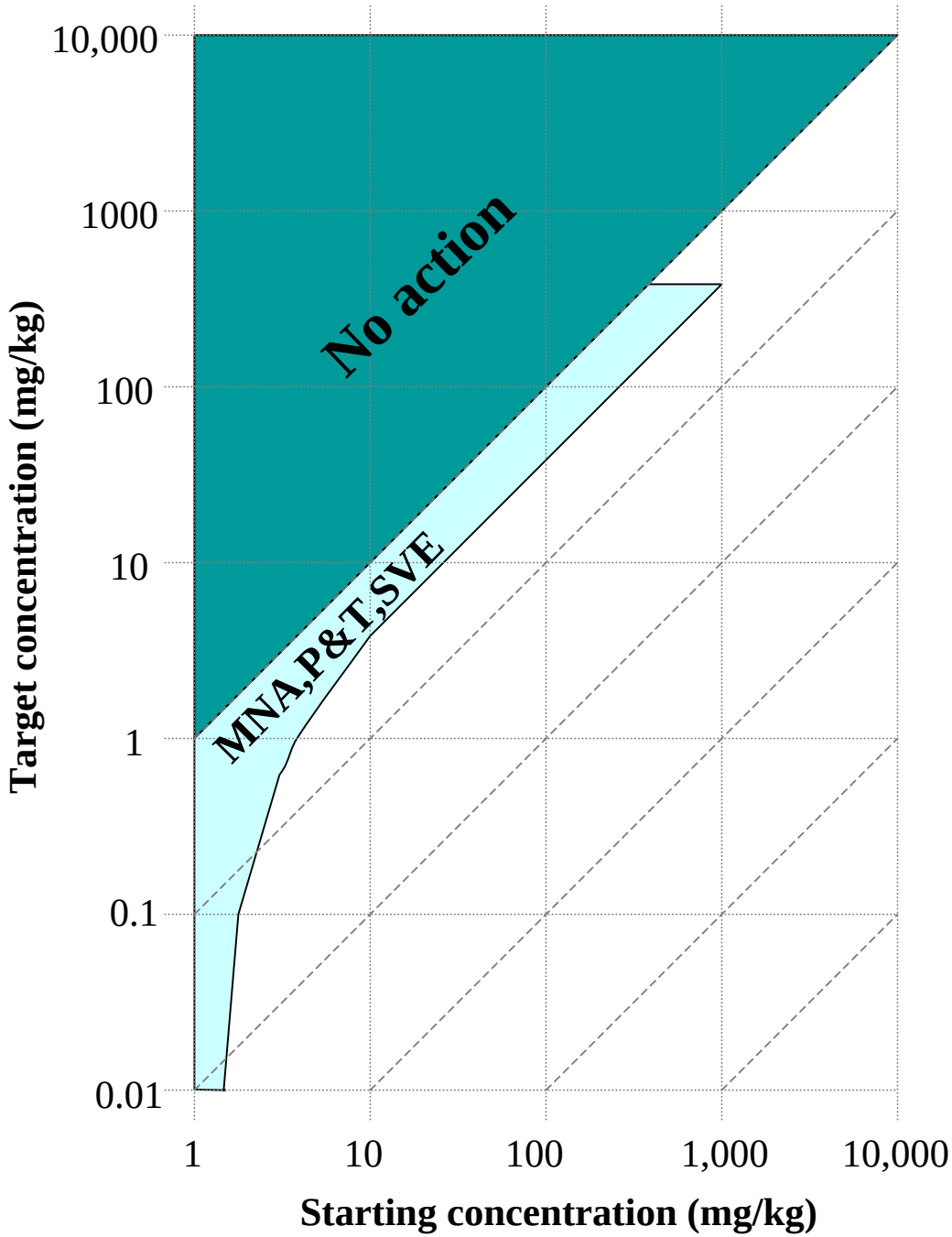


Bioremediation may

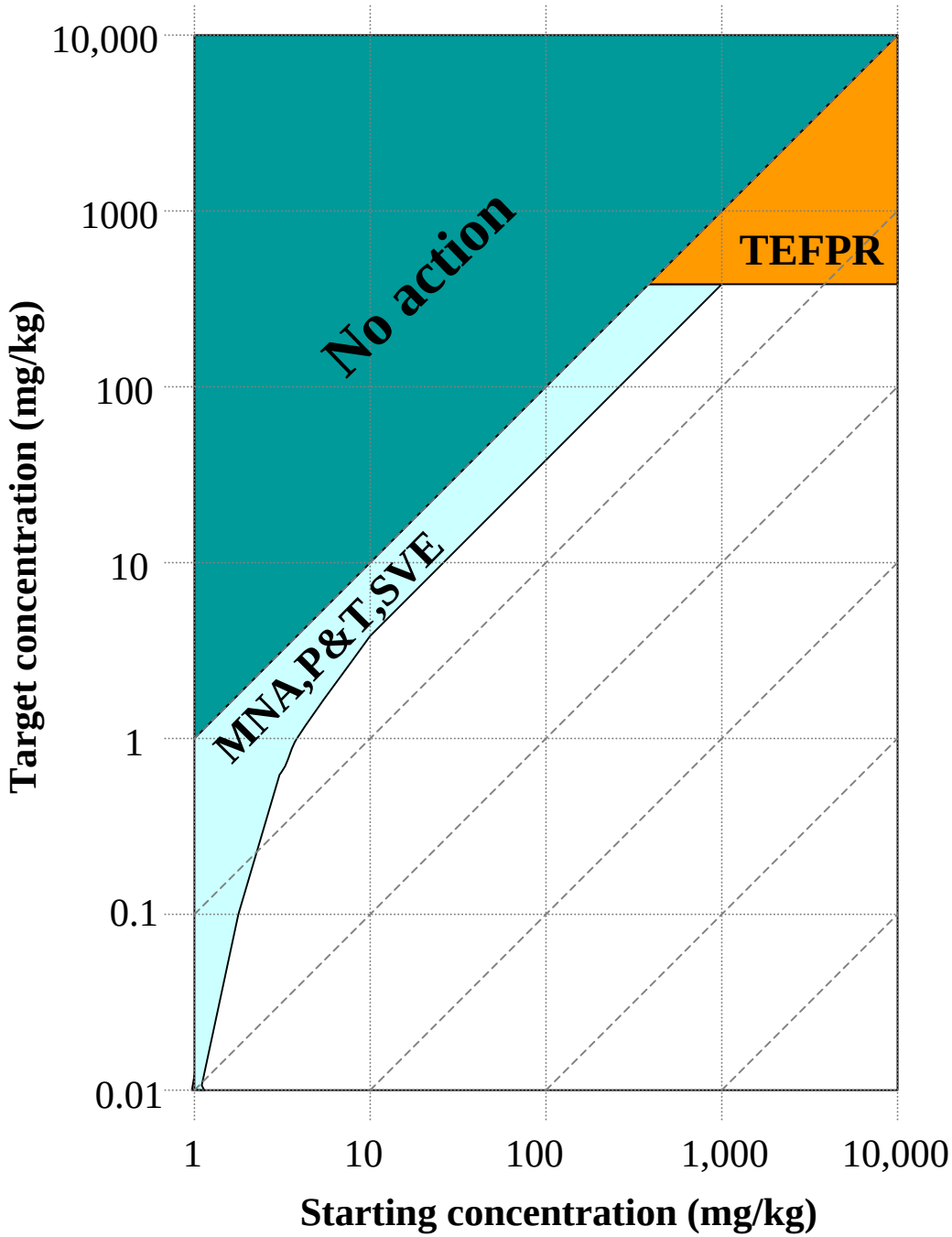
- be discouraged due to quick changes in environmental conditions (T, E_h)
- be encouraged by stimulation and augmentation with little competition



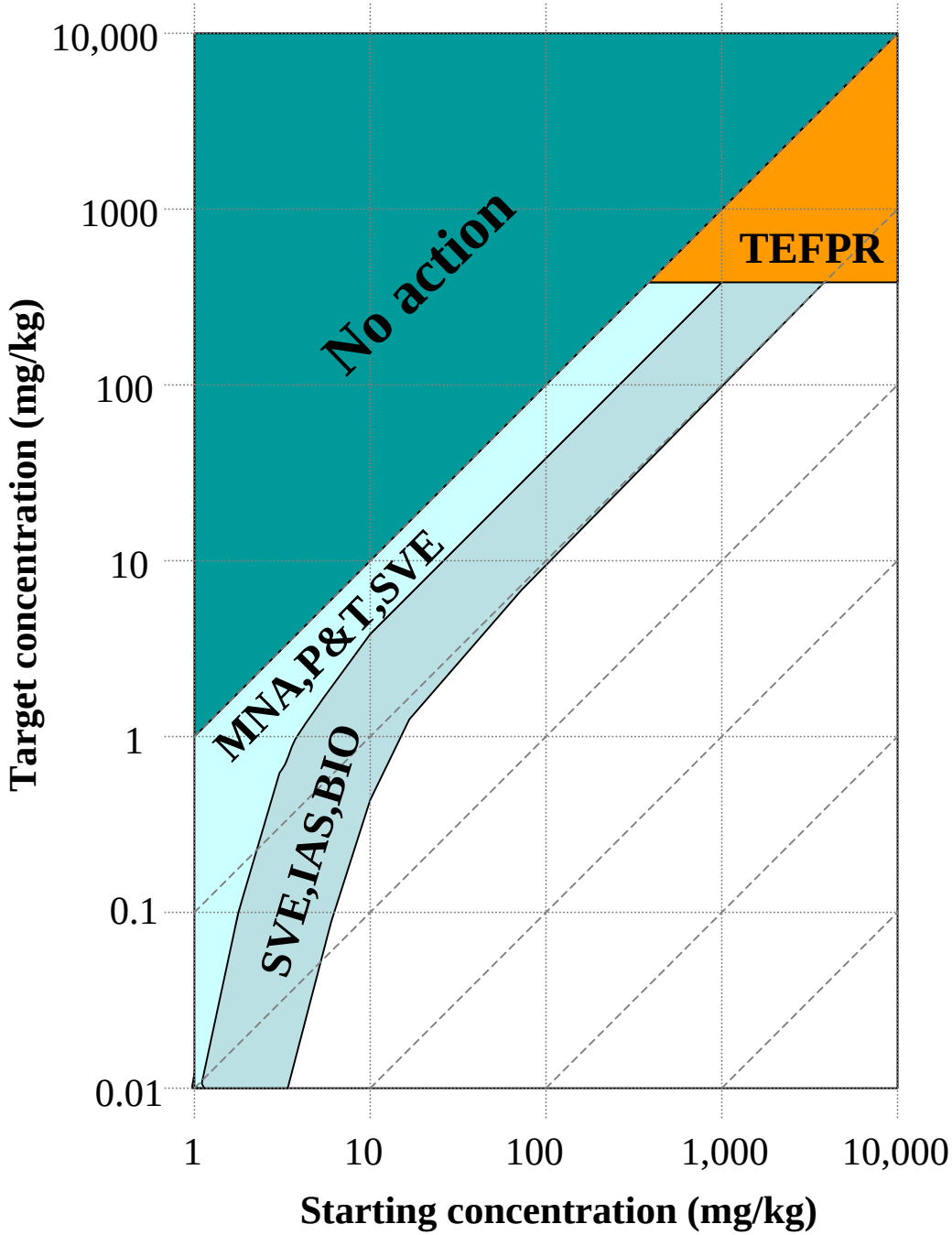
Domains for treatment options



Domains for treatment options



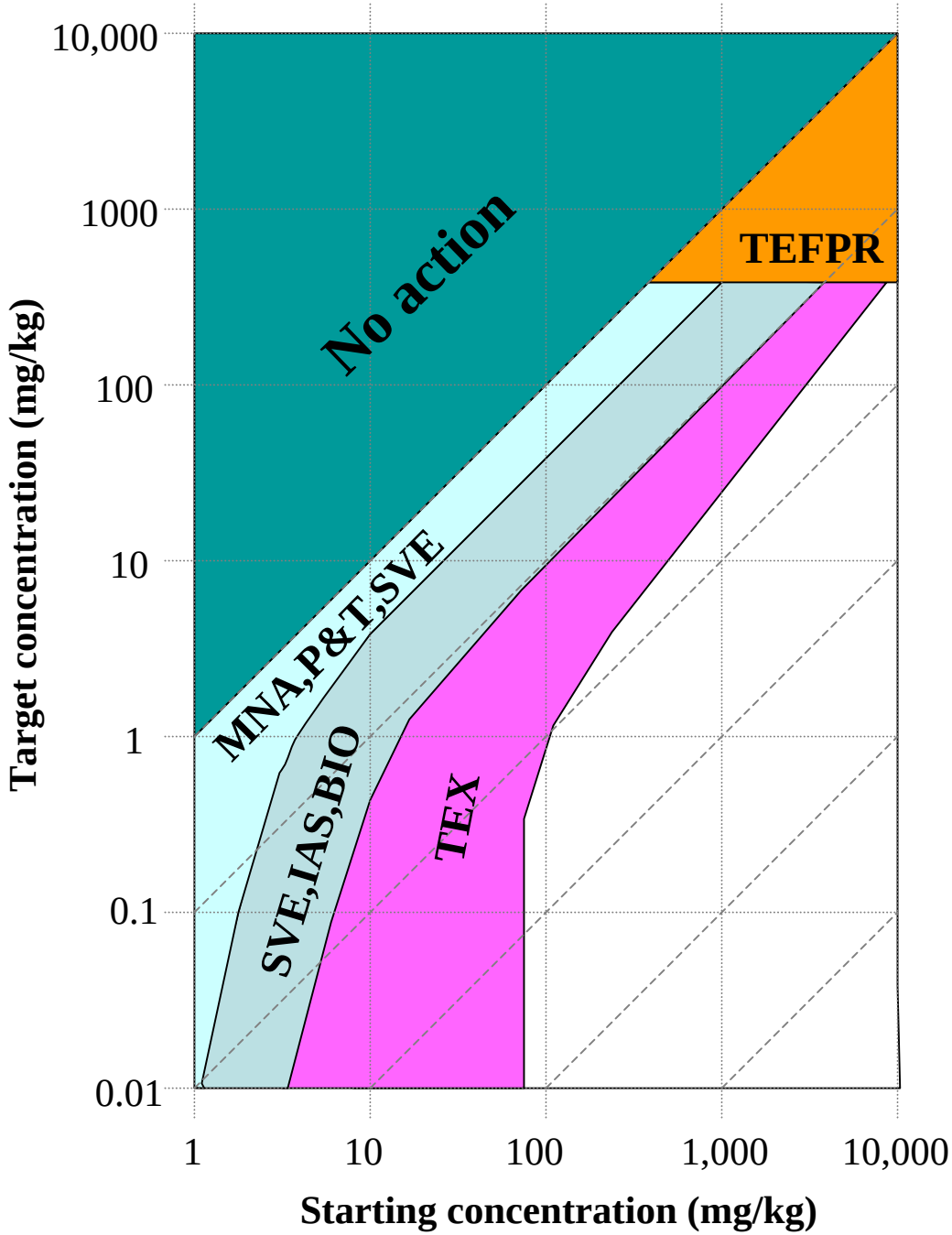
Domains for treatment options



Domains for treatment options

Abbreviations

TEFPR – thermally enhanced free product recovery

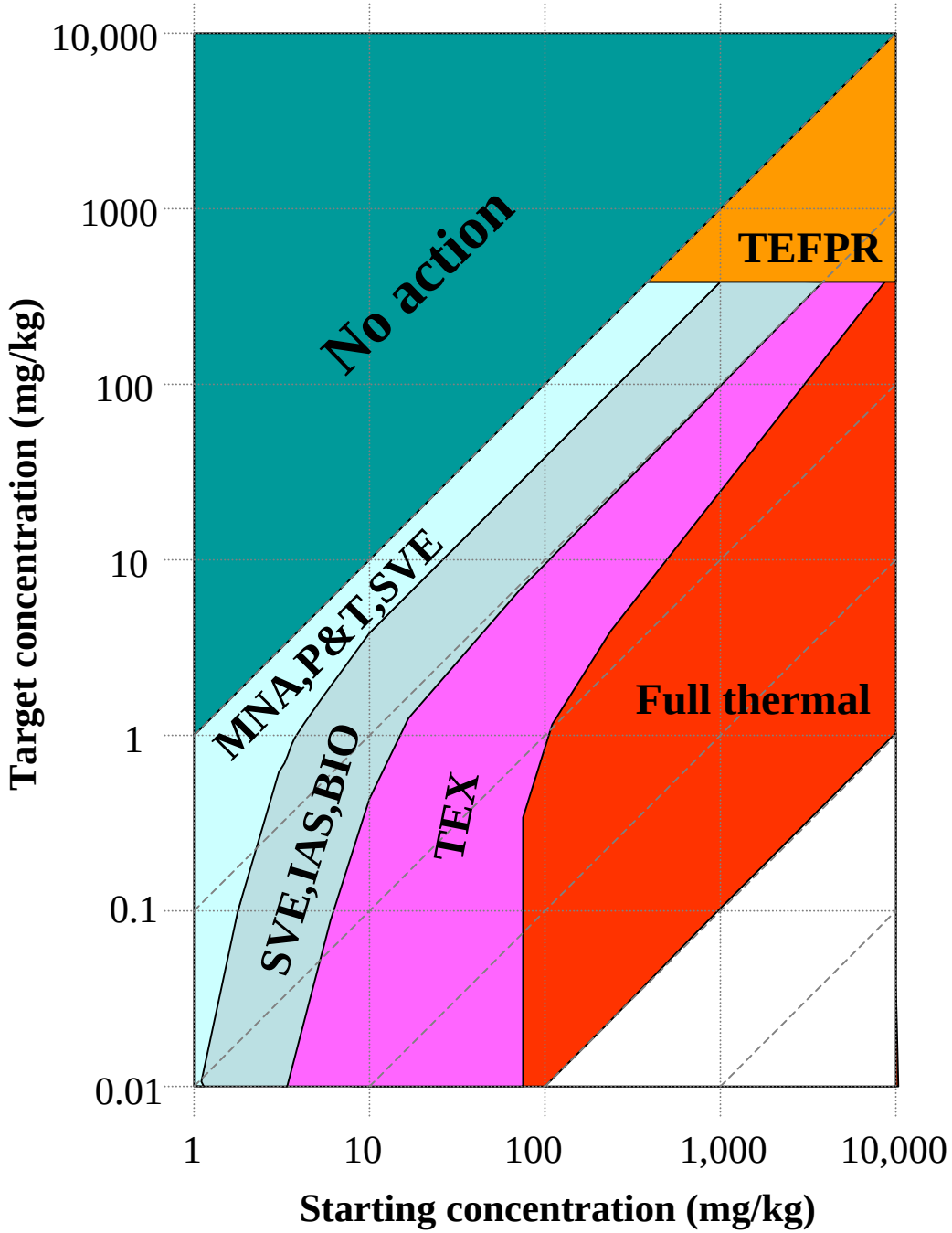


Domains for treatment options

Abbreviations

TEFPR – thermally enhanced free product recovery

TEX – thermally enhanced X

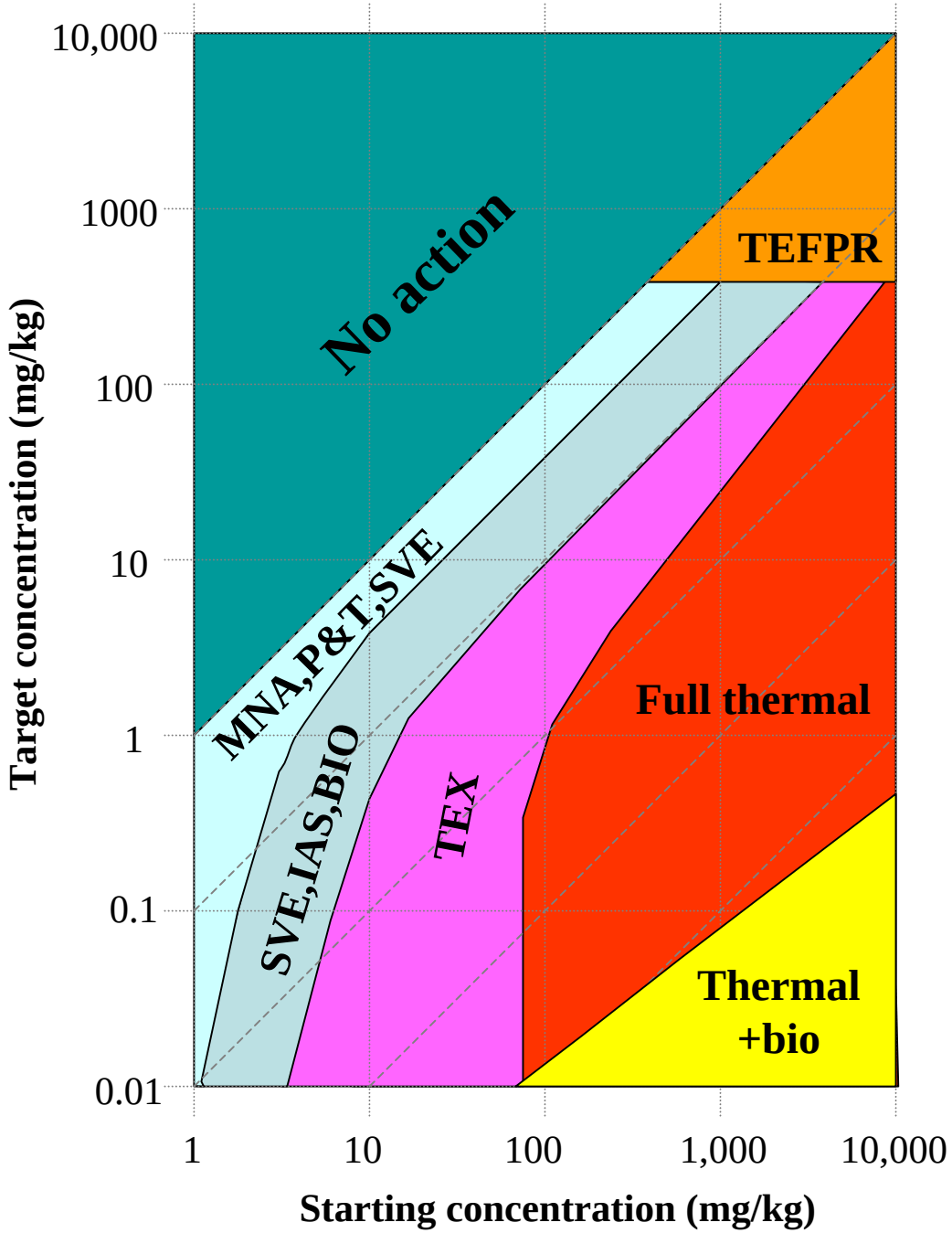


Domains for treatment options

Abbreviations

TEFPR – thermally enhanced free product recovery

TEX – thermally enhanced X

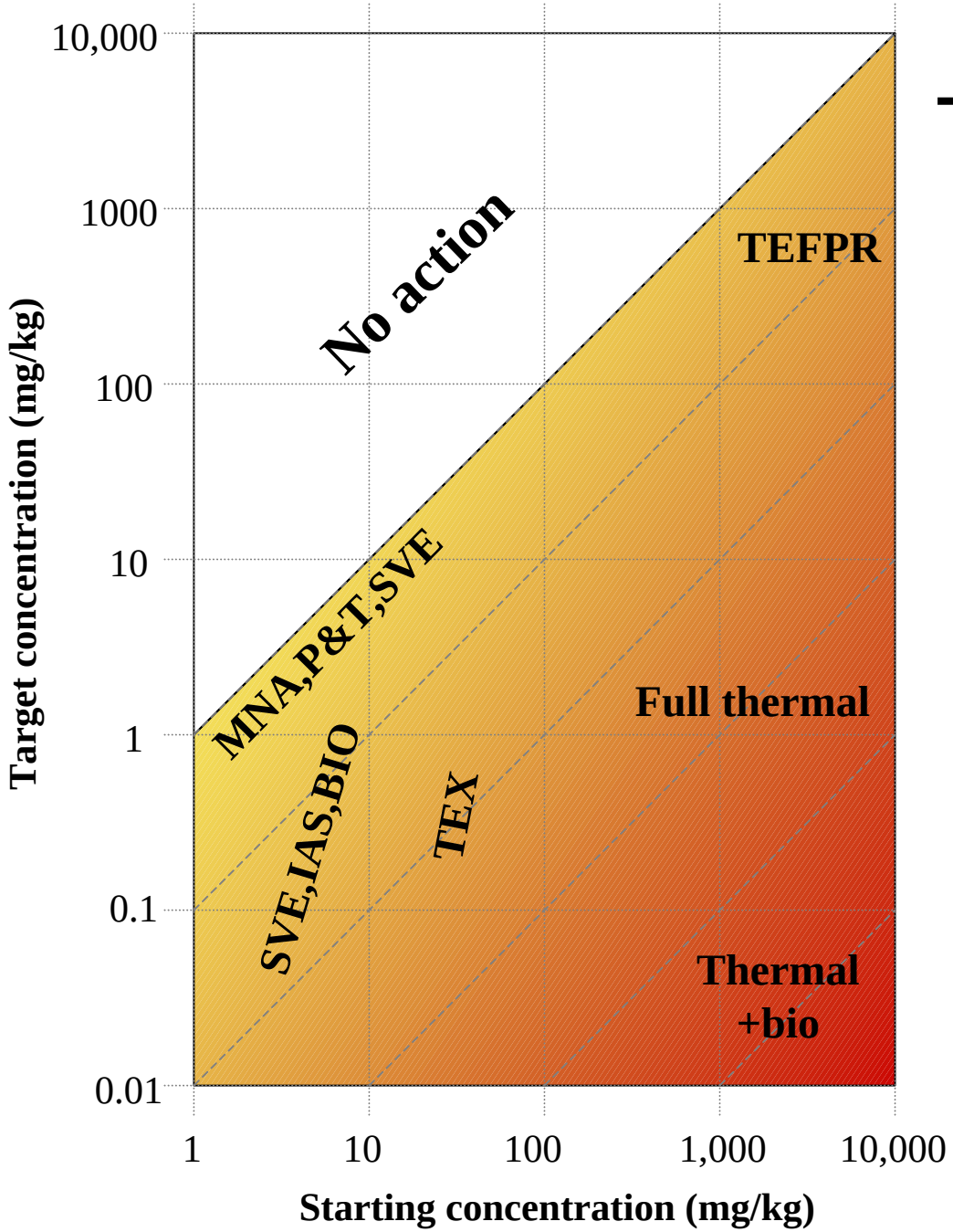


Domains for treatment options

Abbreviations

TEFPR – thermally enhanced free product recovery

TEX – thermally enhanced X



Treatment cost

High

Low

Combo not universally applicable

Relatively high unit treatment cost

Most relevant when remedial goals are very stringent and concentrations high

Conclusions

- It is not simple
- Heating above 40^{o}C favors new microorganisms
- May be beneficial to augment after cool-down
- Geochemistry rules what happens
- Starting and target concentrations are essential
- Case by case evaluation – simple answers are dangerous
- Cost varies dramatically from site to site (so does the most economic technology)